Toward a New Generation of Plasma and Particle Imaging Analyzers

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Abstract- GSFC's Heliospheric Physics Branch (HPB) designs, develops, fabricates and tests flight instrumentation to study ionospheric, magnetospheric, interplanetary and heliospheric physics. Over the past few years, the Branch has focused, among other areas, on neutral atom imaging which allows the remote sensing of otherwise inaccessible plasma populations. Because of the technical difficulties associated with detecting low energy neutrals, the conversion surface is a common component in LENA-type instrumentation and has, itself, been the focus of technology development efforts both at GSFC and at other institutions. As part of the evolution of conversion surface technology instrumentation, the HPB is currently developing an instrument to probe the icy moons of Jupiter and is contributing hardware to the Lo sensor on IBEX, a recently selected SMEX mission, which will probe the heliospheric termination shock.

I. INTRODUCTION

Most of the plasma in the heliosphere is below ∼1 keV in energy. Because the ions and electrons which comprise the plasma are charged, they are confined by electric and magnetic fields to particular regions of space. However, as illustrated in Figure 1, occasionally the ions in the plasma interact with a neutral atom, for example in the Earth's atmosphere, and steal its charge, becoming neutral. Once neutral, the erstwhile ions are no longer confined to a magnetic field line and can travel ballistically for long distances from their original location. Neutral atom imaging techniques observe these neutral products of the ion population to image the plasma population from a distance in much the same way an astronomer uses light to descry far-away planets [1].

Remote sensing these plasma populations provides the opportunity to address fundamental problems that cannot be solved by in-situ observations. These include the coupling dynamics of the ring current, plasmasphere, and ionosphere at the Earth along with magnetopause imaging [2, 3]. At other planets (such as at Mars with ASPERA 3 [4, 5]) low energy neutral atom imaging reveals the global nature of the solar wind/planetary interaction and allows a determination of loss rates leading eventually to a determination of how, for example, Venus lost its water vapor [6].

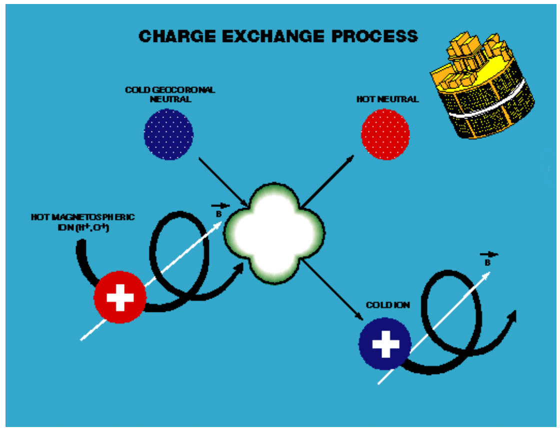

FIGURE 1. The charge exchange process.

Figure 2 shows an example of a LENA image of ionospheric outflow [7] from the Earth's poles. The figure displays neutral hydrogen and oxygen resulting from charge exchange with the Earth's atmosphere. Each of the images covers a bit over 70% of the sky. On the Earth, the auroral oval, home of the northern and southern lights, is indicated in red. The other lines and labels correspond to the Earth's magnetic field.

Table 1 presents a sampling of various neutral atom instruments that have flown in the past [8, 9, 10, 11]. In addition, there are a number of currently planned missions with neutral atom imaging capability. One of these with which the HSB is involved is the Interstellar Boundary Explorer which will attempt to image neutral atoms originating at the termination shock, the outer limits of the solar system.

TABLE 1. A sampling of low energy neutral atom instruments

Spacecraft	Instrument	Science Target
Ulysses	GAS	ISN helium
Astrid-1	PIPPI	low altitude neutral atoms
IMAGE	LENA	ionospheric outflow
Mars Express	ASPERA-3/NPI,NPD	Mars-solar wind interaction

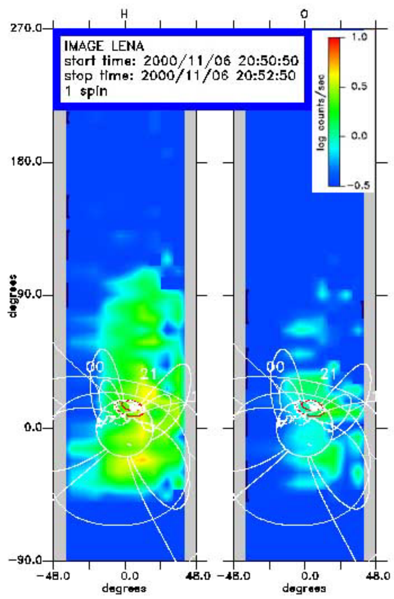

FIGURE 2. LENA image of ionospheric outflow.

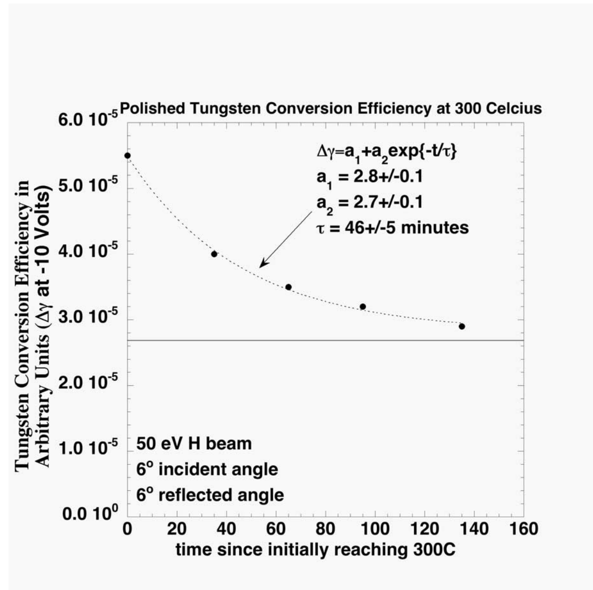

FIGURE 3. Decrease in conversion efficiency as adsorbates are removed at 300 C.

II. APPLICATION TO OUTER PLANETS

At the moons of the outer planets and the Earth's Moon, low energy neutral atom imaging can be used to probe the surface, due to sputtering effected by solar wind and magnetospheric energetic particles. Of particular interest at the outer planets is the possibility of a subsurface ocean at Jupiter's icy moon Europa which could currently host life or have harbored it in the past. Here, the high radiation environment necessitates exceptionally quiet operations requiring mitigation against spurious counts and other effects induced by the harsh environment. Indeed, even at Earth with a more benign radiation environment, the scientific objectives for the Radiation Belt Storm Probes investigations include measuring components of the terrestrial radiation belt environment which cause surface charging, single event upsets, and total dose effects including material degradation.

The turn-over of the icy crust at Europa could push astrobiological signatures of life to the moon's surface, where they would be sputtered off the surface by the local radiation environment and could be observed by orbiting spacecraft.

However, the energies of greatest interest in this case are well-below 1 keV since the typical energies of sputtered products are of the order of a few eV. Furthermore, this would require high mass resolution to differentiate the variety of sputtered products and the ability to detect molecules using, for example, the double stop capability employed on Cassini CAPS [12].

Standard conversion surface techniques are limited at the low energy end to 10-12 eV, because the charge exchange occurs primarily with surface adsorbates with high work functions. To illustrate this point, Figure 3 shows data taken at the now defunct University of Denver (DU) Neutral Beam Facility in the Summer of 2004. This facility, shown in Figure 4, calibrated the LENA instrument prior to launch and has supported the development of other neutral atom prototypes. The Denver facility used laser photodetachment of electrons from a negative ion beam to produce neutral beams. DU was able to produce a neutral beam of either oxygen or hydrogen, from as low as about 10 eV through 1 keV. Although there are other methods for producing neutral beams, this method produced a well-characterized neutral beam in

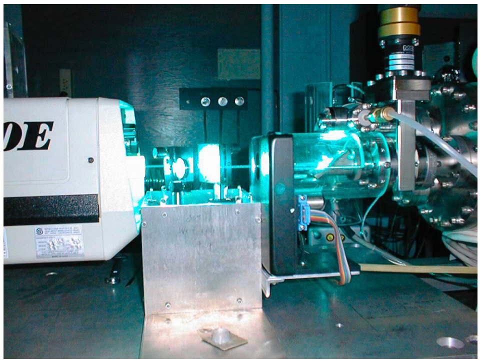

FIGURE 4. The now defunct neutral beam facility at DU.

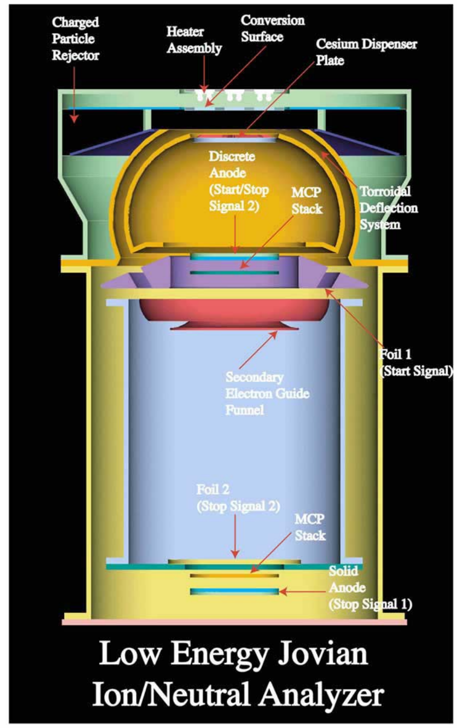

FIGURE 5. A Low Energy Jovian Ion-Neutral Atom Imager.

the ground state.

The data in Fig. 3 were acquired by heating a tungsten conversion surface of the type used in LENA up to a high temperature that was around 300 C (the temperature measurement was made on the stage rather than the surface itself) and holding it there for many hours. An incident 50 eV atomic hydrogen beam impinged on the surface at an angle of 6° and the negative ions produced in the interaction were measured at the specular reflection angle. Plotted on the y-axis is a quantity proportional to the conversion efficiency and plotted on the x-axis is the time in minutes from when the stage initially reached 300 C. The conversion efficiency decreases exponentially over time to a new, lower, asymptotic value, presumably because the adsorbates with which the charge exchange occurs are being driven off with time. In fact, testing at Denver has revealed that, at relatively low vacuums ($\sim 10^{-6}$ Torr), all metal surfaces have essentially the same conversion efficiency, of the order of a percent or so.

Thus, for examining directly sputtered neutral atoms and molecules including those of astrobiological relevance, a new approach is required. Forming negative ions on a clean cesiated surface will lower the measurable neutral atom energy significantly, to the 1-2 eV range, because of the low cesium work function. This will allow such an instrument to probe much lower in energy than the currently flown and planned neutral atom instrumentation.

Cesium, however, is problematic for various reasons. One of these is that cesium deposits on dielectrics inside the instrument which may lead eventually to electrical shorts. Furthermore, providing a clean cesiated surface requires purging the conversion surfaces periodically as any fresh surface will only remain so for a couple of minutes at 10^{-8} Torr as ambient impurities deposit on the surface. Although the vacuum in space may be superior to 10^{-8} Torr, outgassing from the instrument itself and contamination from other sources such as thrusters may deposit on the surface over time. Thus, imaging neutral atoms at these energies requires enough power to heat the conversion surfaces to about 800 C (about 100 Watts per facet for a LENA-type instrument with four facets).

Figure 5 is an example of an instrument designed to achieve the extremely low energy neutral atom imaging required to observe sputtered products. Here, a torroidal deflection system follows the conversion surface allowing an energy resolution of 10%. The converted negative ions then enter a high resolution time-of-flight unit based on the Cassini-CAPS design [12].

III. IMPROVING EFFICIENCY AND GEOMETRIC FACTOR

The central component of this and many other low energy neutral atom imagers is the surface that converts the neutral atoms to ions that are then detected with high efficiency with conventional charged particle detectors. Both the composition of the surface and the geometry of the conversion interaction with the surface require careful consideration for the development of very efficient, high sensitivity imagers.

Thus, the development of higher efficiency low energy

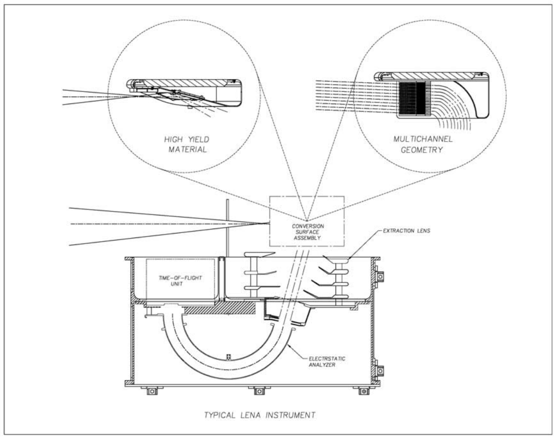

FIGURE 6. Factors influencing instrument throughput.

neutral atom imagers is a dual path activity, as shown in Figure 6. The first activity is the search for high yield surfaces. There are two approaches here. First, the search for materials which, when purged of adsorbates, have high remnant conversion efficiencies. Second is the search for approaches which control the surface properties by eliminating adsorbates such as purged and cesiated tungsten.

The second activity is the search for optimal geometries. Because the conversion process takes place on a surface, techniques that increase the effective surface area will also increase overall throughput and instrument efficiency. One idea is illustrated in the right bubble of Fig. 6. Here, the flat, two dimesional conversion surface is replaced by a matrix of many individual “microchannels” each of which individually functions as a conversion surface. In this way, the two dimensional geometry employed to date and illustrated by the left hand bubble becomes three dimensional, allowing more compact instruments with larger effective conversion surface areas.

IV. CONCLUSION

The responsibility for achieving several of NASA’s strategic objectives belongs in whole or in part to the Science Missions Directorate. Among these responsibilities is exploring Jupiter’s moons, asteroids and other bodies to search for evidence of life. This can be accomplished using extremely low energy neutral atom imaging (< 10 eV). Thus, low energy neutral atom imaging is currently and will continue to be an important technique to support NASA’s Vision for Space Exploration.

To this end, GSFC’s Heliospheric Physics Branch, whose interest in low energy neutral atom imaging began with its lead role on the LENA imager on the IMAGE specraft, is developing the next generation of neutral atom imagers. Improvements on currently flown and planned instrumentation which employ a cesiated conversion surface to effect low work function conversion will be able to search for sputtered products of astrobiological relevance, such as at Jupiter’s icy moon Europa as well as at comets and asteroids. Because of technical problems with cesium though other approaches will also be examined. Furthermore, the HPB is examining two different and complementary approaches to increasing the throughput of these instruments: finding higher efficiency materials and producing stacked surface geometries. However, one major impediment to the development of low energy neutral atom imaging prototype and flight instruments is the current lack of high quality domestic neutral atom calibration facility.

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